NPS-52MV8091A

UNITED STATES
NAVAL POSTGRADUATE SCHOOL

AN INVESTIGATION OF BROADBAND MINIATURE ANTENNAS

by

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September 1968

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ABSTRACT:

  This report considers the application of a negative impedance
converter to a short monopole antenna. The theory of short antennas
and an analysis of the negative impedance converter are presented.
The frequency-response characteristics of the negative impedance
converter are analyzed. The performance of each of various miniature
antenna configurations is compared experimentally with that of a 16
foot untuned whip antenna. The nonlinear behavior of the negative
impedance converter is explored experimentally. Also considered is
the manner in which atmospheric noise level influences the design of
antennas intended to operate in the frequency region below the VHF
band.

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ACKNOWLEDGEMENT

Chapter 1

INTRODUCTION

The electronics field is characterized by progressive
miniaturization of equipment, with integrated circuits providing
the present momentum for this trend. This feature of the elec-
tronics field has not generally been shared by the antenna field.
Traditionally, antenna size has been dictated by the wavelength of
the radiated carrier. Only in the past few years, with the advent
of the space program, has there been any consistent dedicated interest
in size reduction of antennas.

Recently, some work on "small integrated antennas" (SIA) has
been reported [Ref. 1,2]. In general, available engineering data on
the SIA is sparse. Furthermore, the theory of their operation has not
been well presented. As concerns the future development of miniature
antennas, it is perhaps unfortunate at this time that general knowledge
of their status stems from reports in magazines rather than from pub-
lications in professional journals.

This report considers "small" monopole receiving antennas. The
theory of these small antennas and the experimental results obtained
as a part of this study are presented.

A. Background Material

A radio antenna may be defined as the structure associated with
the region of transition between a guided wave and a free-space wave,
or vice versa [Ref. 3]. A short antenna is one whose maximum dimension
is much greater than its other two and yet much less than a wavelength
[Ref. 4]. In this report a miniature antenna is defined as a short
antenna.

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A basic problem of short antennas is their large value of capacitive reactance. To obtain maximum power transfer from the antenna to the load, the load impedance must be the complex conjugate of the antenna impedance Z_a (see Fig. 1), or the antenna must be made to appear purely resistive by compensating for its capacitive reactance. The conventional approach involves the use of series inductance to resonate the antenna at a particular frequency.

| a. Geometric | b. Equivalent Circuit | c. With Matching Network |
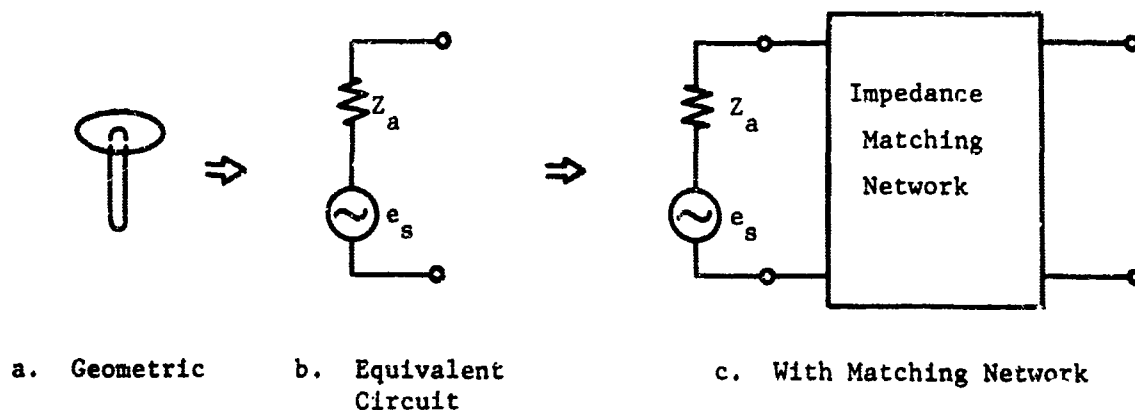
FIG. 1. MINIATURE ANTENNA REPRESENTATIONS.

This method is severely limited, however, by inductor ohmic losses and by the narrow bandwidth resulting from the inherent high Q of short antennas.

Alternate broadband impedance-matching techniques involve the use of active circuits [Ref. 5]. The methods are generally one of two types. The first type we call impedance-level matching. Using this approach a high-impedance short monopole is connected to a high-impedance device such as a field-effect transistor. A low-impedance small loop is connected to a low-impedance device such as

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a common-base transistor amplifier. No effort is made to obtain an exact conjugate match. Some work on impedance-level matching has been reported [Ref. 6]. Impedance-level matching is not considered further in this report.

The second type of broadband impedance matching using active circuits is called negative-impedance matching in this report. This approach uses negative impedance converters (NIC) to approximate a complex conjugate impedance match at the antenna terminals. A NIC is a two-port network that converts an external impedance Z, connected to one port, into a negative impedance -Z at the other port as shown in Fig. 2. The theory of NIC's is well established. Such devices have

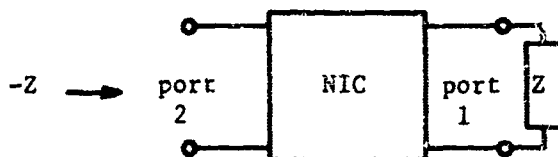FIG. 2. NEGATIVE IMPEDANCE CONVERTER REPRESENTATION.

been used for years in repeaters on long telephone lines [Ref. 7-10]. The NIC is gaining acceptance as a standard tool in network synthesis [Ref. 11].

This report presents results obtained using a NIC with miniature antennas. Figure 3 is a photograph of one of the miniature antennas and the NIC breadboard circuit which were designed, built and tested as a

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part of this study. The antenna in Fig. 3 is a 2 1/2 inch monopole
with a 2 1/2 inch top hat. Data are included comparing miniature
antenna performance with that of a whip antenna. Analyses of the
short antenna and the NIC are also presented.
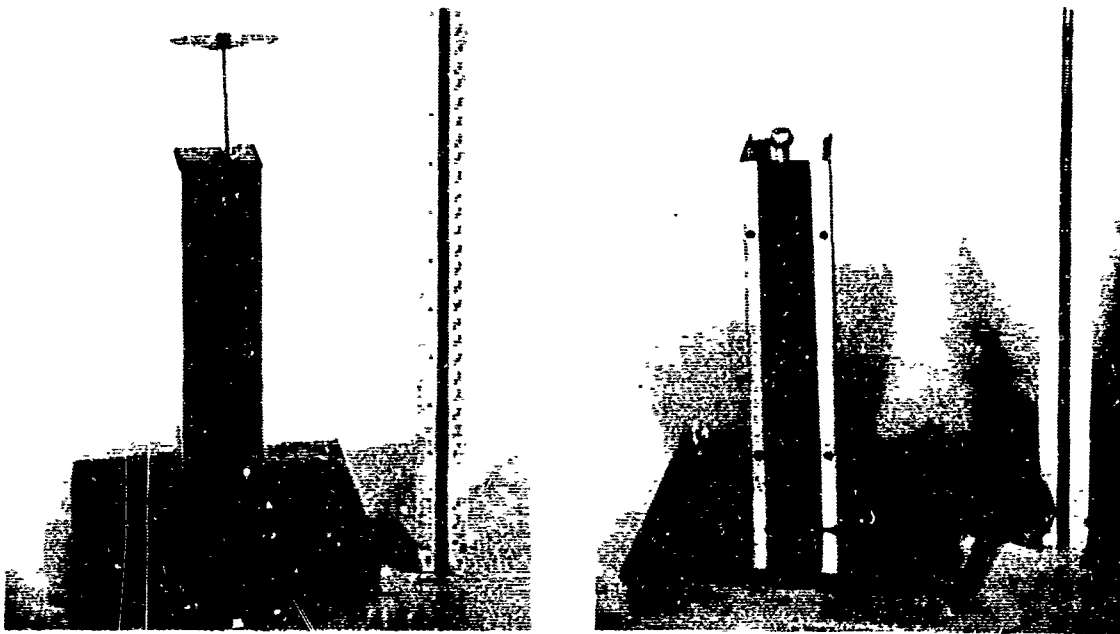
FIG. 3. MINIATURE ANTENNA AND NIC PHOTOGRAPHS.

B.   Plan of the Report

Chapter 2 presents the important results obtained from this
study. The manner in which atmospheric noise level influences design
of low-frequency antennas is considered in Chapter 3. The theory of
short monopole antennas and an analysis of the NIC are contained in
Chapter 4. Chapter 5 details the experimental procedure used to
compare the performance of a miniature antenna with a 16 foot whip
antenna. Conclusions and recommendations are listed in Chapter 6.
Appendix A develops the relations pertaining to the frequency response
characteristics of a NIC. A list of references is provided.

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Chapter 2

RESULTS

This section compares the performance of the miniature antenna
with that of a whip antenna. The results of a test to determine non-
linearity of the NIC are also included.

A.   Comparative Performance of Miniature Antennas

Signal levels obtained with a miniature antenna were compared with
those obtained with a 16 foot untuned whip antenna by using the system
of Fig. 4. Performance curves for a 2 1/2 inch monopole with a 2 1/2
inch diameter top hat and for a 10 inch monopole with a 10 inch diameter
top hat are shown in Fig. 5. Table 1 shows the comparative gain of
other combinations of monopole length and top hat size using the 2 1/2
inch monopole with the 2 1/2 inch top hat as a reference. Signal sources
are signals of opportunity selected by using a Hallicrafters SX-130
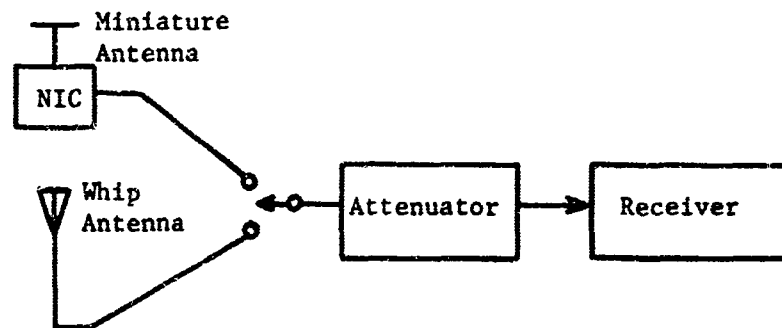
FIG. 4.   EXPERIMENTAL ARRANGEMENT FOR ANTENNA
           COMPARISON TESTS.

communications receiver. A calibrated attenuator between the antenna
providing the stronger signal and the receiver is used to provide
accurate comparisons.

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Gain in db of miniature antenna vs 16 foot whip

+20

+10

0

−10

−20

−30

10 inch stub,
10 inch hat

2½ inch stub,
2½ inch hat

0.4 0.6 1.0 2.0 4.0 6.0 10.0

Frequency in MHz
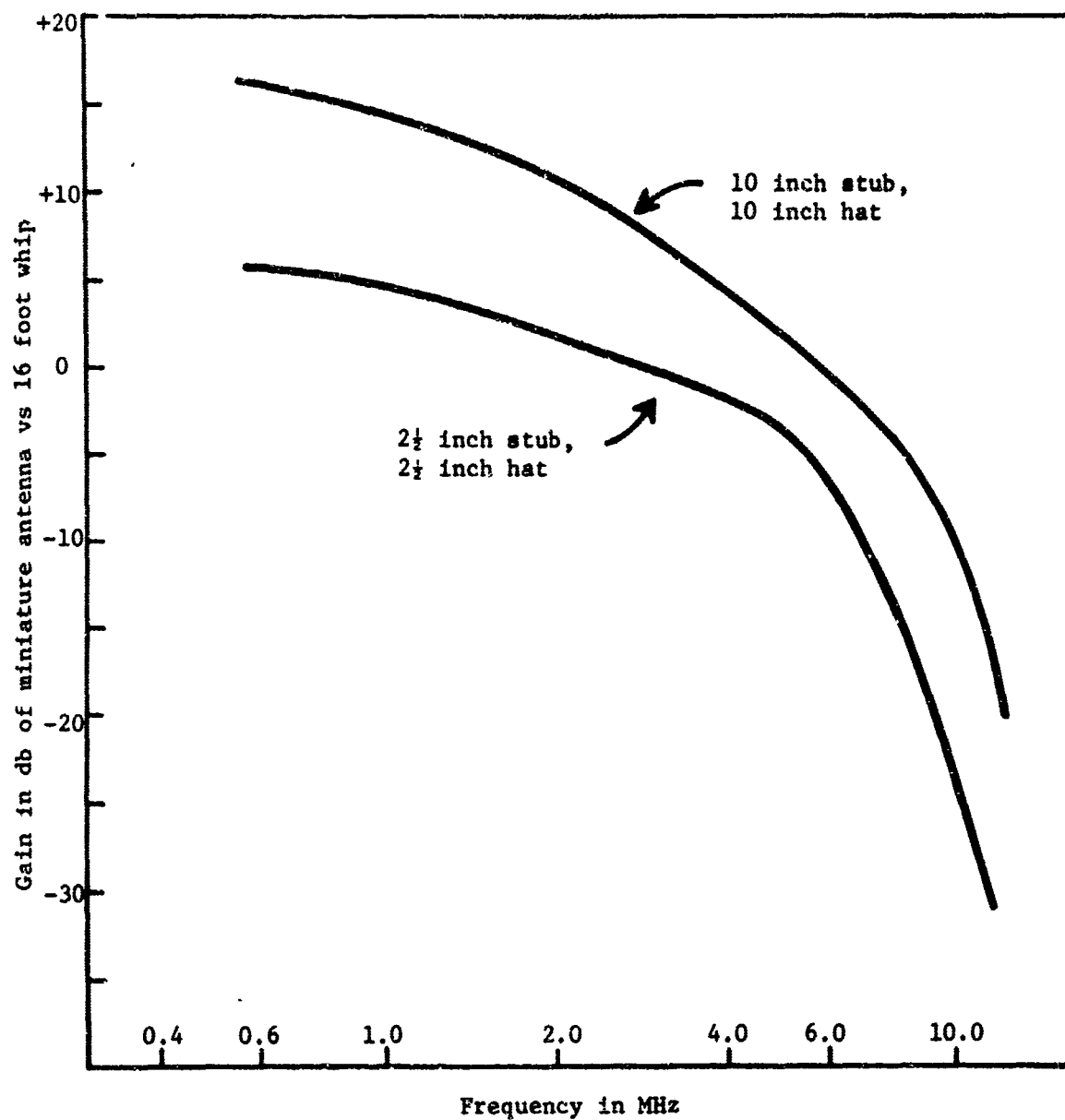
FIG. 5. GAIN VS FREQUENCY OF MINIATURE ANTENNA
RELATIVE TO THAT OF A 16 FOOT UNTUNED WHIP.

Antenna Length (inches)	2½	2½	2½	2½	5	5	5	10	10	10
Top Hat Diameter (inches)	0	2½	5	10	2½	5	10	2½	5	10
Gain Relative To 2½" Ant. With 2½" Hat	−7 db	0 db	+3 db	+7 db	+2 db	+5 db	+9db	+6db	+8db	+11db

TABLE 1. COMPARATIVE GAIN OF DIFFERENT
MINIATURE ANTENNA CONFIGURATIONS.

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Although no noise measurements are made, the noise level is somewhat higher with the miniature antenna than with the whip. This is expected since the NIC used with the miniature antenna provides a voltage gain of 2. Thus, the noise level due to atmospheric noise with the miniature antenna is at least 6 db higher than with the whip. The NIC circuit generates some noise, although this noise should be insignificant compared to atmospheric noise in the region below 10 MHz. Additional noise considerations are contained in Chapter 3.

B. Dynamic Range Considerations

Very strong signals, in particular the signal from a local broadcast station, exceeds the linear signal handling capability of the NIC. The magnitude of the local broadcast station's received signal is ab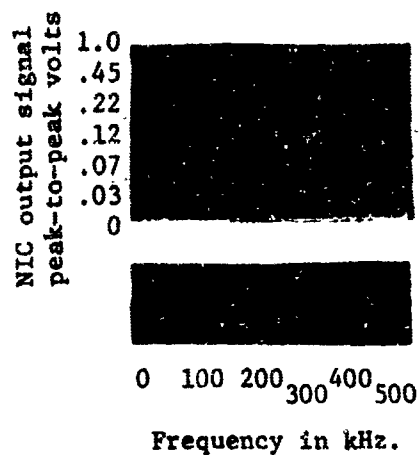out 1 volt peak-to-peak at the output of the NIC   Spectrum analysis of the circuit's output with two simultaneous sinusoidal signals applied yields the results shown in Fig. 6. As shown in Figs. 6a and 6b, a signal which provides a 1 volt peak-to-peak signal at the output of the NIC generates significant harmonic, sum, difference, and third-order mixing signals. Input signals which provide a peak-to-peak level of 0.1 volts at the output of the NIC yield reduced intermodulation signals as shown in Fig. 6c.

A detailed discussion of the experimental procedure used to generate the photographs shown here and additional discussion of these results of the dynamic range test appear in Chapter 5.

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NIC output signal
peak-to-peak volts

1.0
.45
.22
.12
.07
.03
0

0   100 200 300 400 500

Frequency in kHz.

a.   1 volt peak-to-peak signal amplitudes.

Same scale as (a)

Same scale as (a)

b.   1 volt and 0.1 volt peak-to-peak signal amplitudes.

NIC output signal
peak-to-peak volts X 10^2

10
4.5
2.2
1.2
0.7
0.3
0

Same scale as (a)
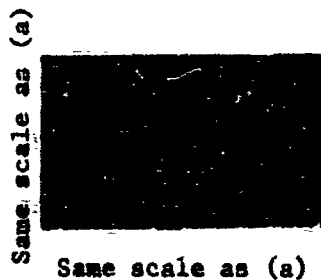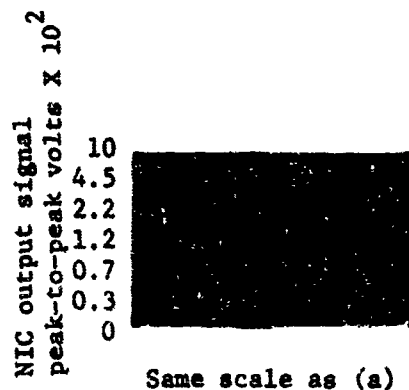
c.   0.1 volt peak-to-peak signal amplitudes.

FIG. 6.   PHOTOGRAPHS OF THE NIC OUTPUT VOLTAGE SPECTRUM
WHEN THE INPUT CONSISTS OF TWO SIMULTANEOUS SINUSOIDAL
SIGNALS.   The input signal frequencies are 200 kHz and
230 kHz.

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Chapter 3

NOISE EFFECTS

A brief discussion of atmospheric noise and its effect on
receiving antenna systems in the frequency region below 10 MHz
is presented in this chapter.

Atmospheric noise level is an important consideration in the
design of receiving systems to operate in the frequency region
below 30 MHz. Curves giving the average field intensity of
atmospheric noise, cosmic noise, and man-made noise versus frequency
are available which show the severe noise level in the frequency
region below 10 MHz [Ref. 12]. In most cases system performance is
limited by this ambient noise level rather than by antenna perform-
ance. No noise measurements were made in this study. This noise-
level limitation is important, however, when specifying antenna
performance.

In the frequency region below 10 MHz so little sensitivity is
required to receive a signal that is above the atmospheric noise level
that either impedance-level matching or negative-impedance matching
are satisfactory as confirmed by Reference 6. In the higher frequency
regions where increased sensitivity is desirable and where receivers
are device-noise limited instead of natural-noise limited, the advantages
of negative-impedance matching over impedance-level matching can be
realized.

The results of Chapter 2 show that the performance of the miniature
antenna relative to a whip deteriorates above 10 MHz. The background

noise in this frequency region is so high, however, that the miniature antenna may still be useful to 20 MHz or more.

One might suspect that, due to the broadband characteristic of the miniature antenna, system noise would be higher than with a narrowband antenna. It must be remembered, however, that in a receiving system, the amount of noise at the output of the system is typically determined by the bandwidth of the narrowband IF amplifier and not by the bandwidth of the antenna.

Chapter 4

ANALYSIS

The theory of short antennas and of voltage inversion negative impedance converters is presented in this chapter.

A. Short Antenna Theory

We define a short antenna as one whose maximum dimension is much greater than its other two and yet much less than a wavelength of the signal of interest. To analyze a short antenna consider its equivalent circuit shown in Fig. 7 [Ref. 4, pp. 294-295]. For the case of a receiving antenna, the quantity e_s represents the voltage induced in the antenna by the electromagnetic wave. The term Z_a is the antenna impedance.
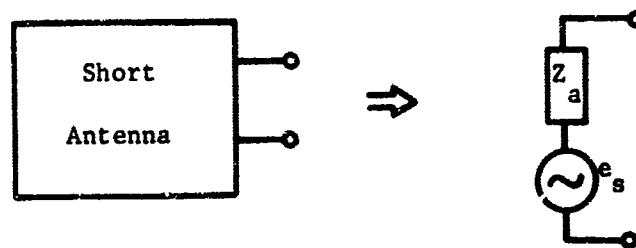

FIG. 7. SHORT ANTENNA EQUIVALENT CIRCUIT.

1. Antenna Impedance

The antenna input impedance Z_a is composed of the input resistance R_a and the input reactance X_a. The input resistance consists of the radiation resistance R_r associated with the radiated power and the loss resistance R_h associated with the power dissipated as heat.

For a vertical monopole whose length L is much less than the wavelength λ of an electromagnetic wave, we assume a linear current distribution with zero current at the top and a current maximum at the base. With such a linear current distribution, the radiation resistance is given as

$$R_r = 40\pi^2 \ (L/\lambda)^2 \ \text{ohms} \tag{1}$$

for a short antenna of length L above a perfect ground [Ref. 4, p. 309].

The input reactance is capacitive for L less than $\lambda/4$. For L much less than λ, an approximate equation for antenna capacitance C_a is [Ref. 4, p. 303]

$$C_a \simeq \frac{2\pi e_v L}{\ln(L/a) - 1} \quad L << \lambda \tag{2}$$

where $C_a = \frac{1}{\omega X_a}$

L = height, meters

a = antenna radius, meters

e_v = absolute dielectric constant of free space = $1/(36\pi) \times 10^{-9}$ farad/meter

For example a monopole with a length L of 2 1/2 inches and a radius a of 1/8 inch has an antenna capacitance C_a of 0.7 pf.

Capacitive top loading is a technique for increasing the effective height of a short vertical antenna. As the size of the capacitive umbrella increases, the effective height increases to a maximum because of the increase in height of the center of charge; the effective height then decreases because of the umbrella's shielding effect on the vertical element [Ref. 13].

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The self-capacitance C_t of the top loading structure is essentially added in parallel with the monopole capacitance C_a to give the equivalent circuit of Fig. 8 for the case of a short antenna with top loading.
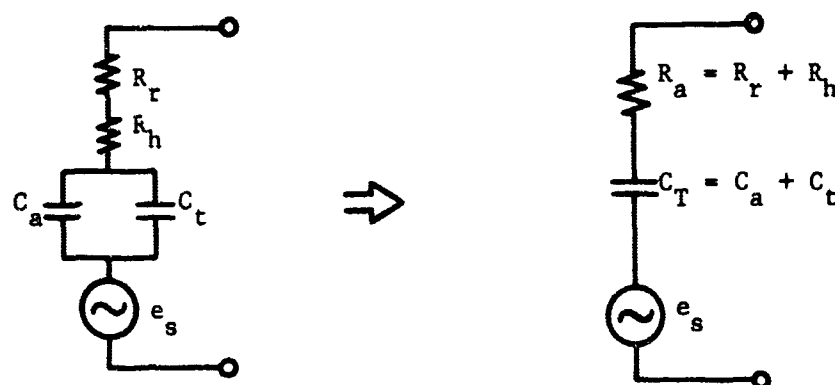
FIG. 8. EQUIVALENT CIRCUIT OF A SHORT ANTENNA
WITH CAPACITIVE TOP LOADING.

The top-loading capacitance C_t is a linear function of the diameter of the geometric form for a disc, sphere, or cylinder, and is shown by the curves of Fig. 9 [Ref. 14]. The length and diameter of the cylinder are equal in Fig. 9. As an example, a 2 1/2 inch diameter disc top hat has a self-capacitance C_t of 2.5 pf.

When a large amount of top loading is used, the antenna current is no longer linear but may be almost uniform; i.e., the antenna current at the antenna base equals the current at its top. This doubles the radiation resistance R_r given by Eq. (1) if a uniform current distribution is assumed:

$$R_r = 80\pi^2(L/\lambda)^2 \quad \text{ohms}. \tag{3}$$

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The actual value of radiation resistance R_r with top loading will be somewhere between that of Eq. (1) and that of Eq. (3).

FIG. 9.   TOP-LOADING CAPACITANCE OF A CYLINDER, DISK,
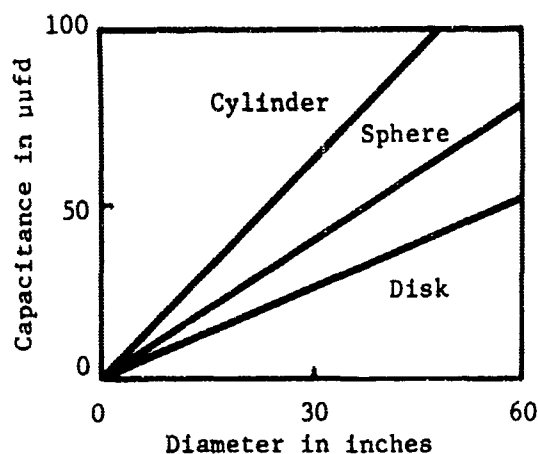AND SPHERE VS THEIR DIAMETERS.

2.   Impedance Matching

The conventional method of matching the short antenna to a 50 ohm load, for example, is to place a series inductance at the antenna base, or possibly at the top of the antenna. The radiation resistance R_r must then be matched through a transformer or other impedance matching network to the 50 ohms. The disadvantages of this method are ohmic losses in the inductor and the fact that the antenna presents a pure resistance at only one frequency.

Even if the inductor could be tuned for multiple frequency operation, R_r is also frequency sensitive, and the matching network must also be tuned. Very little bandwidth is available about the fixed resonance frequency since the antenna reactance, even with top loading, is much larger than R_r for very short antennas. Thus, the short monopole antenna has a very high Q and a subsequent narrow bandwidth.

The matching technique used in this study involves the use of negative capacitance to neutralize the antenna capacitive reactance

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over a wide frequency range, thus providing a broadband antenna.
The parallel equivalent circuit of Fig. 10, which is derived from
that of Fig. 8, is used for this analysis. Since the antenna equivalent
circuit is sharply resonant (high Q), the approximations of Fig. 10
are useful. The ohmic loss resistance R_h of Fig. 8 is neglected in
Fig. 10 because it is usually much smaller than the radiation resistance
R_r.
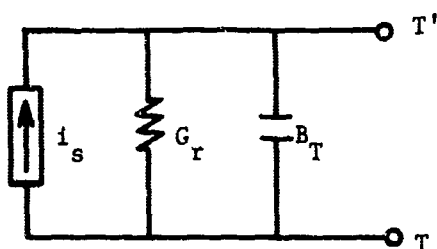
$$Q = \frac{X_T}{R_r}$$

$$X_T = \frac{1}{\omega C_T}$$

$$B_1 = \frac{-X_T}{R_r^2 + X_T^2} \approx -\frac{1}{X_T}$$

$$G_r = \frac{R_r}{R_r^2 + X_T^2} \approx \frac{1}{Q^2 R_r}$$

FIG. 10. PARALLEL EQUIVALENT CIRCUIT OF A SHORT ANTENNA
WITH CAPACITIVE TOP LOADING.

Within the limits of the approximations of Fig. 10, a negative
capacitance $-C_n$, when shunted across the antenna terminals T-T', reduces
the circuit to a signal source and its associated resistance. The
capacitive antenna reactance is canceled over a broad frequency range
where the approximations apply and where the antenna appears to be short
and hence is highly capacitive. The resistance matching problem is
handled by an emitter-follower stage, following the negative-capacitance
circuit, having an output impedance of 50 ohms.

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B. Theory of Voltage Inversion Negative Impedance Converters

A negative impedance converter (NIC) is defined in Chapter 1.
A voltage inversion NIC converts impedance (see Fig. 2) using a
voltage generator as shown in Fig 11 [Ref. 8]. A simple analysis
of the circuit of Fig. 11 shows that the impedance seen at the input
is the negative of the impedance connected to the output.
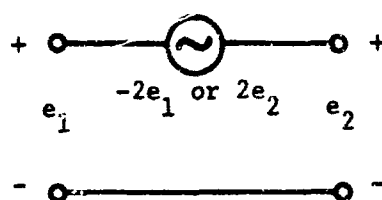
FIG. 11. VOLTAGE INVERSION NEGATIVE IMPEDANCE CONVERTER
          EQUIVALENT CIRCUIT.

To realize the model of Fig. 11, we use an amplifier having a
voltage gain of 2, an infinite input impedance and a zero output
impedance. The resulting circuit, shown in Fig. 12, reduces to
Fig. 11 if A_v equals 2. From Fig. 12,

$$e_1 = i_1 Z + A_v e_1 \qquad (4)$$

or

$$e_1 = i_1 Z + 2e_1 \quad \text{if } A_v = 2$$

from which

$$\frac{e_1}{i_1} = -Z. \qquad (5)$$

An advantage of using this particular voltage inversion NIC is the
availability of $2e_1$ for driving the receiver directly or preferably
through an emitter follower isolation and matching stage.

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FIG. 12.   IDEAL VOLTAGE INVERSION NIC EQUIVALENT CIRCUIT.

Instability is a problem, of course, when working with negative
impedances. For example in Fig. 12 if Z is a capacitance and the
input is open, the circuit is unstable and will oscillate. A capacitor
as large or larger than the negative capacitance must be connected
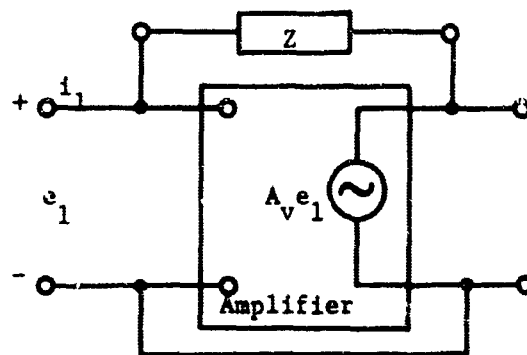across the input to prevent oscillation.

A realizable NIC cannot, of course, contain an amplifier with an
infinite input impedance and zero output impedance and with no phase
difference between input and output over an infinite frequency range.
The finite input impedance places a low-frequency limit on the NIC's
application, and the finite output impedance limits its high-frequency
use. An additional high-frequency limitation, and the most severe
limitation in this application, is the range over which the amplifier
gain A_v equals 2 without appreciable phase difference between input and
output. A detailed analysis of these limitations appears in Appendix A.

Another deviation from the ideal is the limited dynamic range of
the amplifier (non-linear behavior with high-level input signals). This
effect is considered further in Chapter 5.

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C. Analysis of Circuit Used

The circuit used to match the short antenna to a receiver is shown in Fig. 13. The first stage is a field-effect transistor source follower to provide an input impedance of approximately one megohm. Two common-emitter stages Q_2 and Q_3 and an emitter-follower stage Q_4 are held to a total voltage gain of plus 2 by voltage feedback; i.e., $A_v = \dfrac{R_4 + R_8}{R_4}$. The voltage feedback also reduces the output impedance to approximately three ohms, a value well below the output impedance of the emitter follower Q_4 without voltage feedback. C_n provides the impedance Z in Fig. 12 and controls the amount of negative capacitance $-C_n$ available at the input to the NIC. The emitter follower Q_5 is used primarily for isolation between the NIC
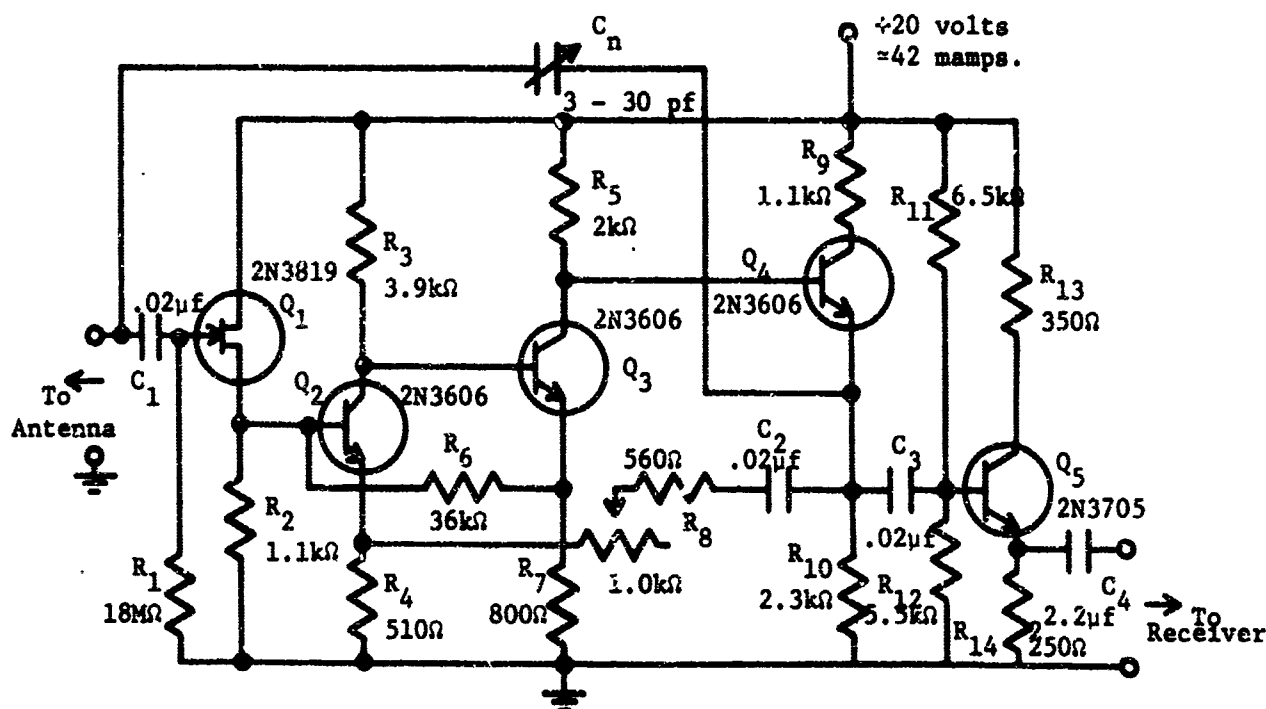
FIG. 13.   VOLTAGE INVERSION NIC CIRCUIT DIAGRAM.

and the receiver. This stage is not designed to present a particular output impedance to any given receiver.

The circuit of Fig. 13 can handle a 4.5 volt peak-to-peak signal level measured at the output. Larger signals saturate and cut off one or more of the stages. As noted in Chapter 2, significant non-linear behavior is observed with one volt peak-to-peak signal level at the output.

Chapter 5

EXPERIMENTAL PROCEDURE

Figure 14 shows the experimental arrangement used to compare
the miniature antenna performance with that of a 16 foot untuned whip.
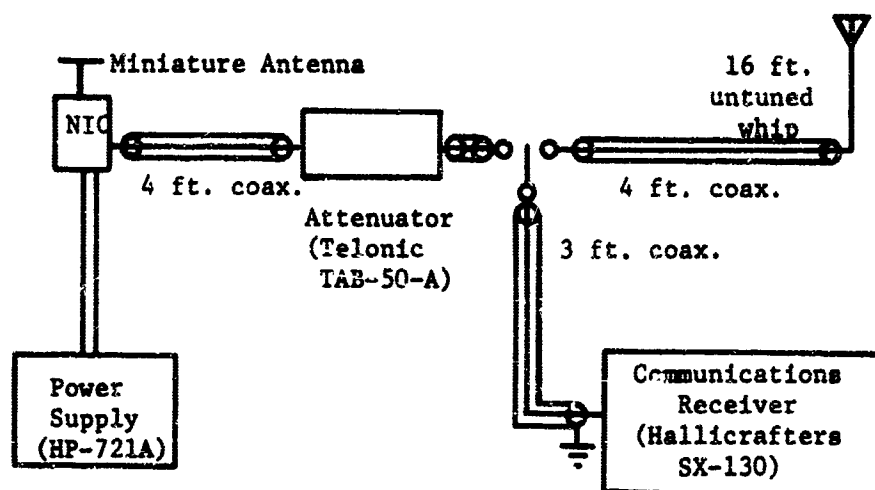
FIG. 14. EXPERIMENTAL ARRANGEMENT FOR COMPARING THE PERFORMANCE
OF A MINIATURE ANTENNA WITH THAT OF A 16 FOOT UNTUNED WHIP.

The base of the whip is approximately 2 feet off the ground, and
the miniature antenna is approximately 6 feet above the ground. No
ground planes are used.

To compare the two antennas at a particular frequency, a signal
of opportunity is obtained with the receiver; the attenuator is then
adjusted so the signal strength meter on the receiver gives the same
reading using each antenna. If the 16 foot whip gives the stronger
signal, the attenuator is used with the whip rather than as shown in
Fig. 14.

The arrangement of Fig. 14 is also used to compare the different
short antenna and top hat combinations. With each combination the NIC
is adjusted to just cancel the antenna's capacitance; that is, the
amount of negative capacitance is increased to a point just short of

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oscillation. This adjustment also gives the best performance in each case, as expected. A signal of opportunity at 1010 kHz is used for this comparison test.

Initially, the above experiments were attempted at the Naval Postgraduate School. However, a 1 kilowatt broadcast station about two miles away made measurements impossible. The broadcast signal level is approximately one volt peak-to-peak at the NIC output, exceeding the small-signal linearity limit of the circuit. Harmonics and mixing signals generated in the NIC by the broadcast station's signal are troublesome even at frequencies above 10 MHz. To ensure the absence of very strong signals, a remote residence on the central California coast about 30 miles from the nearest broadcast station was used as a site for making measurements.

To confirm the nonlinear properties of the NIC when handling large signals, a two signal test was conducted using the arrangement shown in Fig. 15.
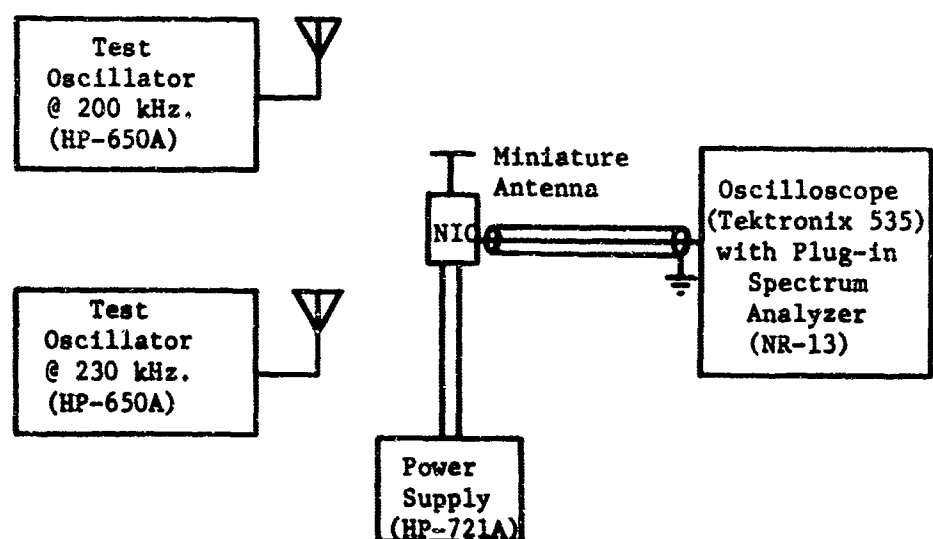
FIG. 15.   CIRCUIT USED TO DETERMINE
          THE NONLINEAR BEHAVIOR OF THE NIC.

The two antennas shown on the oscillators in Fig. 15 are each
actually 2 foot lengths of wire very near the miniature antenna.
The test oscillators are set to give equal one volt peak-to-peak
signals at the NIC output for one test, unequal signals of one
volt and 0.1 volt peak-to-peak for the second test, and equal 0.1
volt peak-to-peak signals for the last test. The results of these
tests are shown as Fig. 6 in Chapter 2.

Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

A.   Conclusions

Several conclusions may be drawn from this study. Some of the
more important results are as follows:

1.   In the medium-frequency and high-frequency bands, system
performance is usually limited by the atmospheric noise level rather
than antenna performance.

2.   A voltage inversion negative impedance converter can be
used to match a short monopole antenna over a broad frequency range
in the medium-frequency region.

3.   A 2 1/2 inch monopole with a 2 1/2 inch diameter top hat
and a NIC for matching compares favorably with a 16 foot untuned whip
as a medium-frequency receiving antenna.

4.   A limitation of the NIC antenna is significant nonlinear
distortion of large signals due to amplifier nonlinearity in the NIC.

5.   Performance of the NIC antenna at high frequencies is limited
by the maximum frequency at which the amplifier in the NIC can provide
a voltage gain of 2 with negligible phase shift.

B.   Recommendations

This study indicates some areas where further investigation is
warranted.

1.   The high-frequency performance of the NIC could possibly be
extended by judicious selection of transistors and additional engineering
effort to minimize the phase shift of the NIC amplifier at higher fre-
quencies.

2.   The current inversion negative impedance converter (rather
than the voltage inversion NIC) could possibly be applied to miniature
antennas, with improved high-frequency performance resulting.

3.   The application of negative impedance converters to miniature
transmitting antennas is worthy of consideration.

4.   Sensitivity of the miniature antenna NIC configuration should
be measured.

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Appendix A

ANALYSIS OF FREQUENCY LIMITATIONS

OF THE VOLTAGE INVERSION NIC

This Appendix analyzes the frequency response of a voltage inversion NIC having finite input impedance, nonzero output impedance, and a nonzero amplifier phase vs frequency characteristic. To simplify the analysis problem, with a slight sacrifice in accuracy, each deviation from the ideal amplifier with a voltage gain of 2 is considered separately.

First, consider a finite input impedance as shown in Fig. A-1.
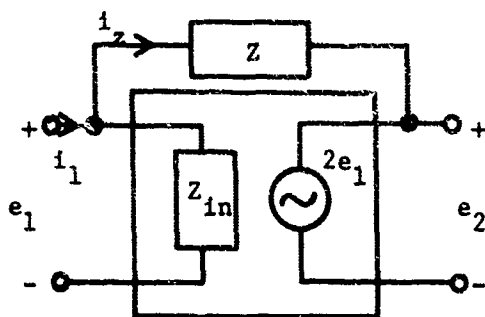

FIG. A-1.   EQUIVALENT CIRCUIT OF VOLTAGE INVERSION NIC
WITH FINITE INPUT IMPEDANCE.

From Fig. A-1,

$$e_1 = i_z Z + 2e_1 \qquad (6)$$

and

$$e_1 = (i_1 - i_z)Z_{in}$$

or

$$i_z = i_1 - \frac{e_1}{Z_{in}} \, . \qquad (7)$$

Substituting Eq. (7) into Eq. (6) yields

$$e_1 = i_1 Z - \frac{e_1 Z}{Z_{in}} + 2e_1$$

which after rearranging gives

$$-e_1 \left[1 - \frac{Z}{Z_{in}} \right] = i_1 Z.$$

The desired negative impedance is

$$\frac{e_1}{i_1} = -Z \left[\frac{1}{1 - \frac{Z}{Z_{in}}} \right]. \qquad (8)$$

For the case of Z a capacitive reactance and Z_{in} a pure resistance, Eq. (8) becomes

$$\frac{e_1}{i_1} = -\frac{1}{j\omega C} \left[\frac{1}{1 - \frac{1}{j\omega C R_{in}}} \right] = \frac{1}{R_{in} - j\omega C} \simeq -\frac{1}{j\omega C} = -Z, \quad R_{in} \gg \frac{1}{\omega C} \qquad (9)$$

Thus, a finite value of NIC input resistance R_{in} affects the low-frequency performance of the NIC to the extent shown in Eq. (9).

Now consider the effect of a finite output impedance as shown in Fig. A-2. From Fig. A-2,
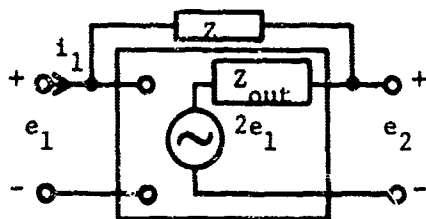

FIG. A-2. EQUIVALENT CIRCUIT OF VOLTAGE INVERSION NIC
WITH FINITE OUTPUT IMPEDANCE.

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$$e_1 = i_1(Z + Z_{out}) + 2e_1.$$

Then,

$$\frac{e_1}{i_1} = - Z \left[1 + \frac{Z_{out}}{Z} \right]. \tag{10}$$

For the case of Z a capacitive reactance and Z_{out} a pure resistance, Eq. (10) becomes

$$\frac{e_1}{i_1} = - \frac{1}{j\omega C} (1 + j\omega C R_{out}) \simeq - \frac{1}{j\omega C} = - Z \text{ when } R_{out} << \frac{1}{\omega C} \tag{11}$$

Thus, a finite value of NIC output resistance R_{out} affects the high-frequency performance of the NIC to the extent shown in Eq. (11).

Consider next the effect of a practical amplifier whose performance deteriorates with increasing frequency. For simplicity, assume the amplifier gain as a function of frequency is

$$A_v = A \left[\frac{1}{1 + j\frac{f}{f_c}} \right] \tag{12}$$

where f_c is the -3db voltage cutoff frequency. Then, substitution of Eq. (12) into Eq. (4) and setting A equal to 2 gives

$$e_1 = i_1 Z + 2 \left[\frac{1}{1 + j\frac{f}{f_c}} \right] e_1. \tag{13}$$

From Eq. (13)

$$\frac{e_1}{i_1} = Z \left[\frac{1}{1 - \frac{2}{1 + j\frac{f}{f_c}}} \right] = - Z \left[\frac{1 + j\frac{f}{f_c}}{1 - j\frac{f}{f_c}} \right]$$

or

$$\frac{e_1}{i_1} = - Z \left[1 + j2\frac{f}{f_c} \right] \text{ for small values of } \frac{f}{f_c}. \quad (14)$$

Thus, a small phase shift in the amplifier is increased when it appears in the formula for negative impedance.

There are, therefore, two reasons why NIC performance deteriorates with increasing frequency: the finite value of NIC output resistance and phase shift between NIC input and output with increasing frequency. When only a small negative capacitance is required, and when the NIC output resistance is small, the NIC phase shift is the primary cause of degraded performance as frequency increases. The phase shift creates a complex impedance rather than a true negative capacitance as seen by the antenna. Consequently, a standing wave is developed, and power transfer from the antenna to the NIC and the receiver is reduced.

DOCUMENT CONTROL DATA · R & D

Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1 ORIGINATING ACTIVITY (Corporate author)	2a. REPORT SECURITY CLASSIFICATION
Naval Postgraduate School	Unclassified
Monterey, California 93940	2b. GROUP

3. REPORT TITLE

An Investigation of Broadband Miniature Antennas

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Technical Report – September 1968

5. AUTHOR(S) (First name, middle initial, last name)

Andrew D. Harris — Captain, U. S. Marine Corps
Glen A. Myers — Assoc. Prof., Naval Postgraduate School

6 REPORT DATE	7a. TOTAL NO OF PAGES	7b. NO. OF REFS
September 1958	36	15

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO.	NPS-52MV8091A
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Naval Ship Systems Command
	Code 6050

13. ABSTRACT

This report considers the application of a negative impedance converter to a short monopole antenna. The theory of short antennas and an analysis of the negative impedance converter are presented. The frequency-response characteristics of the negative impedance converter are analyzed. The performance of each of various miniature antenna configurations is compared experimentally with that of a 16 foot untuned whip antenna. The nonlinear behavior of the negative impedance converter is explored experimentally. Also considered is the manner in which atmospheric noise level influences the design of antennas intended to operate in the frequency region below the VHF band.

DD FORM 1473 (PAGE 1)

S/N 0101-807-6811

A-31409

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Antenna						
Monopole antenna						
Receiving antenna						
Miniature antenna						
Subminiature antenna						
Small antenna						
Impedance converter						
Negative-impedance converter						
Short antenna						
Broadband antenna						

DD FORM 1 NOV 45 **1473** (BACK)

S/N 0101-807-6821

A-31409